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American Lobster Settlement Index: Looking Back, Looking Ahead 1989-2009

Maine Sea Grant

Looking back / Looking ahead

1989 – 2009

WORKSHOP PROCEEDINGS

19-21 June, 2009

Burnt Island
Boothbay Harbor
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OVERVIEW

Hosted by Bigelow Laboratory for Ocean Sciences and Maine Department of Marine Resources, a workshop celebrating the 20th anniversary of the American Lobster Settlement Index convened some 40 scientists, managers, and industry members and guests from New England and Atlantic Canada who have been involved in the monitoring and research linked to the Index over the years. The workshop's aim was to look back at the accomplishments of the Settlement Index over the past two decades and to set future monitoring, research and outreach priorities for the program. Rick Wahle of Bigelow Laboratory and Carl Wilson of DMR coordinated the gathering. Maine Sea Grant helped defray meeting costs. The meeting was divided between two half-day sessions, starting with oral and poster presentations on past and current research and ending with a discussion prioritizing future directions. The island retreat also provided a relaxed atmosphere featuring a Friday evening lobster bake and a Saturday afternoon hike at nearby Damariscove Island, a location that figured prominently in the beginnings of the Index.

Oral and Poster Presentations

Setting the stage for the workshop, **Rick Wahle** (Bigelow Laboratory) gave an overview of the background and history of the Settlement Index including its geographic expansion and research milestones achieved since its beginnings in the late 1980s. The key breakthrough at that time was the application of suction sampling to the problem of quantifying newly settled lobsters in their nursery habitats. Over the years suction sampling expanded along the coast of New England into New Brunswick and Nova Scotia. Building on past success with diver-deployed passive postlarval collectors, a vessel-deployed version opened the possibility for sampling at depths and locations that are otherwise unsafe or impractical for divers. Collectors had been used in a diver-deployed manner since the 1990s, but a recent fisherman-scientist collaboration supported by the Northeast Consortium resulted in redesign that allows collectors to be deployed with standard commercial trap hauling gear. Since 2007, the use of collectors has expanded dramatically through coastal Atlantic Canada, New England and offshore areas (Fig. 1) promising new insights into patterns of lobster settlement.

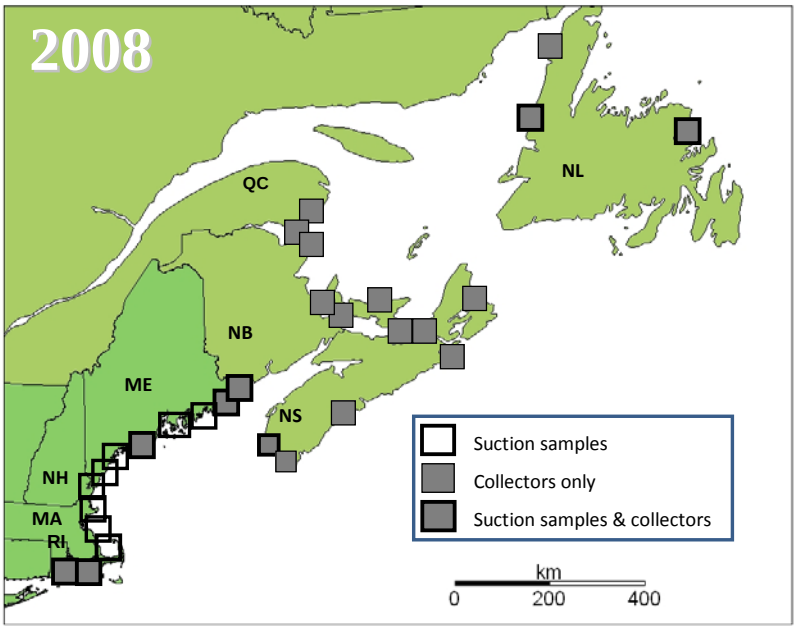

Fig. 1. Locations included in the American Lobster Settlement Index as of 2008 by diver-based suction sampling or passive postlarval collectors. Each box represents a multi-site region.

Stan Cobb (University of Rhode Island) provided a deeper historical context. In the late 19th and early 20th century the natural sciences experienced a philosophical shift from observational to hypothesis-driven experimental approaches. Students of lobster biology mirrored that shift. Cobb cited Francis Herrick's detailed observations and meticulous drawings as a classic example of the observational emphasis of the time. But of some 90 papers published on the American lobster by 25 authors between 1890 and 1910 there is an emergence of experimental studies on larval development, behavior and nutrition. Many of the questions Herrick and his contemporaries posed, such as how to determine lobster age, how far larvae disperse, and sources of natural mortality, are still at the center of research today. Careful observation and monitoring at the organismal and population level remain at the scientific core.

Our understanding of lobster larval production and transport stems from a combination of field sampling and numerical modeling. **Lew Incze** (University of Southern Maine) reviewed progress on modeling the pelagic-benthic coupling between larval transport and settlement. The coupled bio-physical model of lobster larval transport developed by Xue et al. (2008. *Ecol. Modelling* 210:193-211) is the latest iteration of several published modeling approaches over the past two decades. This model now suggests recruitment is more locally derived than previously thought, although the potential for long distance dispersal increases with the distance from shore females hatch their eggs. Incze indicated that larval transport models would benefit from a better understanding of larval and postlarval distributions and behavior, larval mortality, indices of coastal convergence and divergence, and higher spatial resolution of egg production.

The spatial scale at which annual settlement fluctuations are synchronous can speak volumes about the about the environmental processes driving larval supply. **Andrew Pershing** (University of Maine and Gulf of Maine Research Institute) revealed provocative new insights on the role of weather. He explained that the separate regional settlement time series are coherent (vary in synchrony) over much of the Gulf of Maine, but are less so between the Gulf of Maine and southern New England. Moreover, he examined the strength of correlations between settlement and several indicators of regional atmospheric conditions. Indicators of the strength of atmospheric pressure gradients and resultant regional wind patterns turn out to be good predictors of regional fluctuations in lobster settlement.

While Pershing's work used modeled atmospheric data from the National Center for Atmospheric Research (NCAR), **Mahima Jaini's** (University of Maine) poster described how satellite-derived data from NASA are being used to evaluate spatial correlations between settlement and temperature anomalies on the sea surface to identify oceanographic features and processes that may be important to lobster larval supply.

Newly settled young-of-year (YoY) lobsters are relatively easy to distinguish from older year classes by their small size, but because of variable growth rates, size-based age determination becomes less reliable as lobsters grow. Still, absent other reliable age indicators, body size remains the most commonly used tool. In a poster presentation, **Charlene Bergeron** (Bigelow Laboratory and University of Maine) reported the results of how she fine tuned size definitions of YoY and 1-year-old lobsters sampled during the annual early autumn survey. Her approach finds the non-overlapping size range combination for the two age groups that maximize the coefficient of determination between them. The resultant size ranges are similar to those

produced by modal analysis using Multifan software, and they differ by region depending on the prevailing thermal regime. This project is a spin-off of Bergeron's Masters thesis research in which she is developing a general model of lobster growth from settlement through sexual maturity that is applicable in constrasting thermal regimes.

Indeed, lobster size-distributions in nurseries can say a lot about environmental influences on growth and mortality in the early post-settlement years. **Louise Gendron** (Institut Maurice-Lamontangne, Quebec) presented her long-term research on lobster populations in the rocky nurseries of the Magdalen Islands in the Gulf of St. Lawrence. Annual diver-based visual monitoring along fixed transects since 1995 has provided data on lobster year class strength and growth inferred by the analysis of size-frequency distributions. Her studies suggest that inter-annual variability in settlement is correlated with advection indices and egg production. Furthermore, her data suggest it will be feasible to follow cohorts from the nurseries into more open habitat sampled by trawl surveys, a transition made at about age 3+ years. This mean forecasting Magdalen Island fishery recruitment from the settlement index may be possible in the near future. The Magdalen Island lobster population is considered to be largely isolated from other populations in the Gulf region, and therefore, self-sustaining. It will be important to include Gendron's time series with the annual reporting of other settlement index data from Atlantic Canada and New England.

Analyses of genetic structure provide insights on the degree of connectivity among populations. **Gareth Harding** (Bedford Institute of Oceanography) reviewed the results of a comprehensive analysis of the genetic structure of the American lobster metapopulation over the species' entire geographic range (Kenchington et al. 2009, *Molec. Ecol.* 18: 1654-1667). Lobsters from the northern end of the range (Gulf of St. Lawrence) have low genetic diversity compared to those in the Gulf of Maine and southern New England. The authors interpret these results to suggest that populations in the southern glacial refuge retained much of the genetic diversity present prior to glaciation, whereas only a few founder events re-established populations in the north after the glacial retreat. Issues that confound our understanding of genetic structure include inadvertent introductions of lobsters from other regions. Sampling and analysis of genetic structure at a finer spatial scales, coupled with a better understanding of larval and adult movements, would help further resolve the metapopulation structure.

Do locations consistently supplied with plenty of larvae also have consistently robust harvests? **Bob Steneck** (University of Maine) reviewed the 10-year *tour de force* he led with **Carl Wilson** (Maine DMR) during the 1990s that included diver-based suction sampling and visual surveys, as well as sea sampling of the commercial catch. The multi-layered project demonstrated that juvenile "hot spots" along the coast are also harvesting hot spots, encouraging hopes that settlement can be a useful tool in fisheries forecasting. Steneck pointed out that although visual surveys are not optimum to quantify YoY lobsters, they do sample larger areas and capture the early benthic phase signal which is the result of the previous 2-3 years of settlement. He emphasized that to increase our predictive power we need to understand the processes and mechanisms of lobster recruitment that lead to distinct patterns in space and time.

Clearly, physical attributes of the water column and sea bed play an important role in the spatial distribution of the American lobster. A poster presentation by **Jui-Han Chang** (University of Maine) described a habitat suitability model exploring the importance of factors such as benthic habitat quality, depth, temperature, and salinity in predicting the spatial distribution of juvenile and adult lobsters found in the Maine nearshore trawl survey. The next step in Chang's dissertation research will be to include the Settlement Index in her predictive model.

Juvenile lobster monitoring in the intertidal is producing similar geographic patterns to the settlement index, as well as new insights on movement and growth. With community volunteers, **Diane Cowan's** *Lobster Conservancy* monitors over 130 intertidal sites along the New England coast, 24 of which are monitored year round. She explained how her 16-year time series from Lowell's Cove, Harpswell, ME, has been showing a markedly seasonal cycle of juvenile lobsters moving into the intertidal zone during the warm months and out to deeper grounds during the winter. The overall density at this site and others along the coast has been on the increase over the years. Her tagging efforts at two locations in Maine are producing detailed information on growth during the first few years of life.

Michael Fogarty (National Marine Fisheries Service) emphasized the need for long-term monitoring of multiple life stages in order to track the consequences of a changing environment. He discussed the projected changes in lobster population dynamics under the great water column stratification associated with warmer temperatures and increasing precipitation anticipated over the coming decades. While southern regions may more frequently see temperatures rise to physiologically stressful levels, in cooler regions, such as the Bay of Fundy, conditions may become more favorable for settlement and growth, thereby dramatically altering the map of lobster fishery productivity.

In Atlantic Canada settlement monitoring by suction sampling has expanded slowly from its starting point in Beaver Harbor, New Brunswick. However, deployments of passive postlarval collectors have spread rapidly through Atlantic Canada. **John Tremblay** (Bedford Institute) discussed the development of the settlement index time series off coastal Nova Scotia. Suction sampling has been conducted in Lobster Bay since 2005 and collectors have been deployed there since 2007. Encouragingly, suction sampling and collector-based data are strongly correlated. Through fisherman-scientist collaborations, collectors have helped expand the spatial coverage of monitoring in Nova Scotia. Tremblay and co-workers hope to continue this monitoring in order to follow lobster year class success.

Michel Comeau (DFO, Moncton, New Brunswick) has been collecting juvenile lobster abundance data in the southern Gulf of St. Lawrence since 1994 using subtidal visual surveys. Data from belt transect surveys provided useful fishery independent data on the status of the stock. But poor visibility has hampered visual and suction sampling efforts in Northumberland Strait. Passive collectors were deployed widely in the southern Gulf in 2008, enabling the first reliable data collection of YoY lobsters.

Peter Lawton (DFO, St. Andrews, New Brunswick) discussed DFO lobster research and its collaborations between the University of New Brunswick and the Atlantic Reference Center concerning passive collectors and biodiversity monitoring. With limited resources Lawton has

managed to maintain an 18-year suction sampling time series in Beaver Harbor, NB. Over the years DFO's bathymetric imagery capabilities have become increasingly sophisticated. These seabed products will be especially valuable to the identification of lobster nursery habitat. Lawton also described recent collaboration with **Remy Rochette** of the University of New Brunswick. Their deployments of passive postlarval collectors in Beaver Harbor illustrate how DFO's academic partnerships engage academic institutions, fishery managers and the fishing industry in research and monitoring. He recommended that the members of the collaborative bear in mind the continuing need to (i) calibrate the passive collectors as a tool in lobster settlement and biodiversity monitoring, and (ii) establish appropriate sea bed mapping classification schemes and habitat suitability modeling.

Discussion Session

The workshop's discussion segment, led by **Carl Wilson** (Maine DMR), was held on Saturday morning. The aim was to prioritize research and monitoring objectives for the Settlement Index. Participants suggested discussion items prior to and during the workshop (Table 1) At the workshop the group picked two items considered high priorities under each of three topic areas:

1. Survey Methodology
    - Seabed mapping
    - Size frequency analysis
2. Ecological Processes & Connectivity
    - Metapopulation dynamics
    - Post-settlement processes & settler-recruit relationships
3. Resource Assessment
    - Settlement to fishery forecast
    - Settlement reference points/thresholds and subsequent management action

Survey methodology: Seabed mapping was seen as vital to the future development of the settlement index. Mapping would not only aid site selection for diver-based and collector-based sampling, it would permit the quantification of suitable nursery habitat, and in turn, enable extrapolation from density estimates to total YoY recruitment. Historically, one of the impediments to large scale recruitment estimates has been the disparities in mapping schemes between the US and Canada and even among the maps used by individual states. The group concluded that instead of relying on international or Federal habitat classification schemes, it would be more helpful to develop schemes that fit the habitat requirements for individual species or functional groups, including the American lobster. But how to do that remains unclear. A future workshop involving both biologists and geologists may be the best way of moving forward on this task.

Refinements in size-frequency analysis were also listed as a priority under the survey methodology topic. This relates to the development of growth models used to track cohorts through time. Refining these methodologies will aid in estimating growth rates during the early benthic phase. Alternatively, despite the higher cost and effort, tagging (e.g., Cowan), has the advantage of providing a direct measure of individual growth. Understanding growth under

environmentally contrasting conditions will help us develop generalized growth models. In the absence of reliable age markers, integrating tagging-based and size-frequency-based approaches (e.g., Bergeron's thesis work) should help refined our understanding of the size-age relationship

Ecological processes: Inferences about metapopulation connectivity from Harding's overview of the Kenchington et al. (2009) paper sparked a good deal of discussion. There was general agreement that effective lobster fishery management will require a better understanding of metapopulation structure. Three advances would help us toward this end: (i) finer spatial resolution of egg production for improved larval transport modeling, (ii) renewed tagging of benthic adults to improve our understanding of population exchange during the benthic life phase, and (iii) finer spatial resolution on population genetic structure to compare to predictions of larval exchange models regarding gene flow among subpopulations.

Knowing the ecological determinants of the post-settlement fate of a cohort is critical to forecasting time trends in the population. Recent analyses suggest it will not be enough to only monitor lobsters from cradle to grave; it will be important also to monitor other agents of natural mortality – such as predators, disease, and adverse environmental conditions - that may alter natural mortality over time (e.g., Wahle et al. 2009, and poster presented at the workshop). These parallel time series and direct evidence of their effects will be important to include in future modeling of post-settlement dynamics.

Resource Assessment: The Settlement Index is used in the US Federal Stock Assessment and by participating states as one of several indicators of the health of the resource. The group discussed the need to define a YoY recruitment reference point that will provide a threshold for management decisions. As the regional data base grows, state and Federal fishery managers will need to decide whether it is appropriate to define reference points as triggers to subsequent management measures. The more fishery scientists understand how YoY recruitment translates to fishery recruitment, the better they will be positioned to set guidelines for the use of Settlement Index reference points.

Conclusions

The workshop achieved its primary objectives of providing a forum to review the accomplishments of the Settlement Index and to prioritize future directions. It reaffirmed the importance of the Index as a powerful tool in understanding lobster early recruitment processes and population dynamics. It will be particularly important to continue to evaluate the Settlement Index as a forecasting tool for later life stages sampled by other monitoring programs such as trawl surveys and traps. Topics not addressed in full include some of the methodological details of the survey, and questions regarding specific ecological mechanisms listed in Table 1.

The structure and future of the collaborative as we move into the next decade will be important to discuss at subsequent meetings. As data time series accumulate in the different regions, they become more valuable. And as we take a more inclusive view, comparing time series in different regions (such as the Pershing study), the more we will need to agree on policies of data use, data sharing, and co-authorship.

Liisted below are the main conclusions and recommendations resulting from the workshop:

- Settlement Index is showing promising signs of being useful as a forecasting tool for fishery recruitment, but it is likely that forecasting models will need to be regionally customized to incorporate factors other than the Settlement Index, such as those that alter natural mortality rates over time. This will be especially important to consider in the context of long-term climate change, short-term environmental perturbations and disease.
- Continue to examine links with parallel environmental time series of both pre- and post-settlement processes, and incorporate these variables as appropriate in modeling cohort dynamics.
- Continue to refine size definitions for age classes, by region, to improve the tracking of cohorts through time.
- Integrate size-frequency-based and tagging-based approaches to develop general growth models.
- Calibrate passive postlarval collectors with suction sampling as a tool in lobster settlement and biodiversity monitoring.
- Calibrate visual transect counts from Magdalen Islands with suction sampling quadrat counts.
- Establish appropriate sea bed mapping classification schemes and habitat suitability modeling over the lobster's geographic range to enable an extrapolation of standing populations.
- Improve the understanding of larval and postlarval development, behavior and mortality in nature.
- Improve spatial resolution of egg production and coastal convergence and divergence zones that influence larval source-sink dynamics.
- Improve our understanding of the role of adult movements in population connectivity.
- Establish guidelines for the use of a Settlement Index as a decision tool in fishery management.

Table 1. Discussion topics identified by participants prior to and during the workshop.

1. Survey Methodology

- Mechanism of collaborations
- Database formats and standardized reports
- Techniques: suction sampling vs. collectors
- Quadrat Size / Belt transects
- Random vs. Sentinel Sites
- Expansion to include PL sampling
- Sea bed mapping
- Size-frequency analysis

2. Ecological Processes & Connectivity

- Climate impacts and explanations
- What is the match of settlement to subsequent ontogenetic phases
- Larval drift nearshore not well resolved by modeling
- Settlement cues
- Meta-populations
- Importance of local vs. distant egg production to recruitment
- Pre- and post-settlement processes
- Changes in growth and natural mortality
- Larval mortality
- Changes in habitat use
- Habitat suitability models
- Use of genetic tools

3. Resource Assessment

- Settlement to fishery forecast
- Nature of collaboration (US, CA, etc.)
- Assessment application (model component or indicator)
- Settlement threshold or trigger
- Management application

ORAL PRESENTATION & POSTER ABSTRACTS
(alphabetized by first author)

Size range definitions for young-of-year and one-year-old American lobsters from size frequency data

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In population studies of lobsters and other benthic crustaceans, following the density of age groups over time allows for valuable inferences about mortality rates and the strength of density-dependent processes influencing population dynamics. Because crustaceans do not have definitive morphological indicators of age, size is most often used as a criterion for age. Young-of-year (age 0+) American lobster collected at the end of the settlement season can be identified as a well defined mode in the size-frequency distribution of lobsters in suction sampling collections. However, there is some overlap in size between age 0+ and one-year-olds (age 1+), and even more so between age 1+ and 2-year-olds (age 2+). The uncertainty in assigning ages by this method therefore hampers our ability to follow the fate of cohorts through time. Past regression analyses examining the age 0+-to-1+ linkage have used size range assignments estimated somewhat subjectively from size distributions by eye. Here we describe two approaches to refine our size definitions for 0+ and 1+ lobsters. One approach involves an iterative process of finding the size range combination of age 0+ and 1+ lobsters that maximizes the coefficient of determination (r^2). The other method involves modal analysis using the program Multifan which provides estimates of the mean and standard deviation for the size range of age groups. We found good agreement between the two methods for three regions that contrast in lobster size-at-age owing to differing thermal regimes. Results suggest that for some regions our size definitions should be altered from those determined by more subjective methods.

Coherence of spatial distribution of settlement, juvenile, and adult American lobster on the coastal Gulf of Maine

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Based on data collected from a fisheries-independent bottom trawl survey from 2000-2007, we developed a two-stage generalized additive model to evaluate the impacts of seven spatial and environmental variables (i.e., latitude, longitude, depth, temperature, salinity, sediment type, distance to sediment edge, and distance offshore) on the spatial distribution of American lobster. The developed spatial suitability model was used to delineate potential spatial distribution of American lobster along the coastal Gulf of Maine. A cross-validation analysis suggests that the lobster spatial distribution can be well predicted by the developed models. The constructed models were then used to estimate the density of juvenile and adult lobsters on the coastal GOM from spring 2002 to spring 2007. The settlement index obtained from a suction sampling survey was compared with the estimated juvenile and adult lobster density to evaluate the coherence of spatial distribution of lobsters of different life history stages. Different time lags, reflecting different growth patterns, are investigated in the coherence analysis. This analysis yields critical

information for a better understanding of spatial and temporal distribution of the American lobsters in different life history stages.

Herrick's contemporaries: The OTHER lobster biologists 1890-1911

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A century ago, the early life history of lobsters captured the attention of a number of natural historians in New England and eastern Canada. Francis Hobart Herrick was prime among them and his two magnificent monographs attest to the depth and vigor of his studies. But there were also scientists who performed remarkable work and contributed to the flowering of lobster biology at the turn of the (last) Century. At least 22 biologists published more than 80 papers over the period 1890 – 1911. Herrick boasted in his introduction to the 1909 (1911) monograph, "Our knowledge of the lobster has increased to such an extent during the past 15 years that in all probability there is no marine invertebrate in the world that is better known". Embryology, larval biology and growth dominated the studies, in support of the many hatcheries active at the time. Victor Emmel, Philip Hadley, H.C. Bumpus, Arthur Mead, Sidney Smith and a host of others laid the scientific foundation for the early life history studies and YoY index we are here to discuss.

Lobster early life stage monitoring and research: the southern Gulf of St. Lawrence perspective

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In the southern Gulf of St. Lawrence (sGSL), the abundance of cryptic-stage American Lobster (*Homarus americanus*) was estimated from 100-m transect lines randomly placed on lobster reefs. These transect lines were surveyed by two SCUBA divers each covering an area 2-m wide on either side of the transect line (400 m^2 per transect). Divers attempted to capture, measure (carapace length), and determine the sex of every lobster observed within the transect zone. In addition, the divers recorded selected habitat characteristics within each transect. On average, abundance of 1 and 2 year-old lobster increased from 1.0 to 6.0 lobster/100m2 between 2000 and 2006 in LFA 23 and commercial landings in 2008 and 2009 (preliminary) have increased to level observed in the 1990s (highest historical landings recorded). In contrast, 1 and 2 year-old lobster abundances remained low in central Northumberland Strait (generally below 1 lobster/100 m^2). As well, an attempt (in the 1990s) to estimate the abundance of young-of-year (yoy) by means of suction sampling in quadrates failed, largely because of very poor visibility that typically occurs in this area after lobster larval settlement (i.e., zero visibility due to fall storms). During 2008, rock-filled collectors were used for the first time to estimate the abundance of post-larval lobster in several areas of the sGSL. The results look promising and the long-term goal is to compare estimates from the sGSL with those in other areas participating in the postlarval collector's network to create a synoptic view of lobster settlement over its full geographical range. Finally,

laboratory work to sort and identify all of the benthic species that settled in these collectors with the goal of using the collectors as another tool to quantify the biodiversity in coastal ecosystems.

Lobster Nursery Habitats: How crowded can they get?

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The American lobster, *Homarus americanus* is reputed to be the quintessential solitary animal and is prone to aggression and cannibalism in captivity. The great abundance of lobster in the Gulf of Maine (ASMFC 2009) begs the question: how can lobster density be so high if members of this species are solitary cannibals? Others have suggested limits to the carrying capacity of the lobster's environment based upon a demographic bottleneck at the time of settlement due to limited available habitat (Fogarty and Idoine 1986, Wahle and Steneck 1991). However, in a 16+ year monthly census (1993-present), postlarval and first-year lobsters were routinely found together under rocks at the intertidal/subtidal interface. We suggest that group living in juvenile lobsters may function as a mechanism to overcome the constraints of limited availability of rocky habitat.

Lobster Population Dynamics in a Changing World -- the Role of Monitoring in Management and Assessment

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Sustained levels of high exploitation rates of American lobster stocks in the United States have transformed the demographic structure of the population to one shifted toward effective semelparity and fishery to one dominated by new recruits. The need for effective monitoring programs at multiple life history stages is essential as an early warning mechanism under these conditions. Larval and post-settlement monitoring programs provide the earliest indicator of possible changes in recruitment levels and their implications for assessment and management. Juvenile and adult survey monitoring programs provide a more proximal indicator of change in the fishery at more immediate time scales. These multistage-multiscale programs also offer the potential to identify critical stages in the life-history where change is most acutely manifest and opportunities to test alternative hypotheses concerning the determinants of change. The potential interaction between climate change and exploitation on lobster productivity highlights the need to continue these monitoring efforts to assess risk to the population and to evaluate appropriate management and mitigation strategies.

Lobster benthic settlement in the Magdalen Islands, Québec, from 1995 to 2008

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Juvenile American lobsters are quantitatively surveyed by SCUBA divers at a nursery ground located in the southeast part of the Magdalen Islands (Québec) since 1995. Lobsters are hand-picked by moving cobbles and digging around boulders to a depth of 10-15 cm. Sampling is done along 1 meter-wide transects lines running perpendicular to the shore between 2-5 m depth. Each year, 5-6 50-meter long transect lines are surveyed from which 250-650 lobsters ranging in size between 5-80 mm CL are collected. Each year, SFDs are computed to extract and characterize modes that are interpreted as instars, based on in situ growth observations (for instars V to VIII), and distinctive and recurrent features of the SFDs through time. Each year, size-at-instar, contributing instars to year classes (YC) and abundance of YC up to age 3+ are estimated. There has been a 30-fold variation in the settlement index (SI) during this 14-year period. Pre-settlement factors such as wind-driven advection and the abundance of the brooding stock account for part of this variation. This 14-y time series provides more than a SI. The large number of lobsters collected each year gives also the opportunity to get an insight of lobster growth and survival during the 3 years they spend in the nursery providing some basis to the study of the linkage between SI and future fishery landings.

Interpreting the genetic structure of the American lobster (*Homarus americanus*), throughout its range, in relation to present-day, adult migrations and larval dispersion

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The population structure of the American lobster was examined by using a subset of 13 of 20 microsatellite DNA markers examined, using spatial analyses. A postglacial northern-edge colonization model was used to explain the relative homogeneity of the northern region relative to the southern population centered in the Gulf of Maine and south to Long Island Sound. The contemporary area of low gene flow demarcating these two regions is best explained by the oceanic regime. Laval lobster dispersion between these two areas would be minimal and one-way with the predominantly southwest flow along the Scotian Shelf. Adult movements of the northern population along the bottom are restricted to shallow local migrations because of avoidance of cool, deeper water. The anomalously diverse lobster population sampled at Val Comeau, NB, is believed to be an artifact of the release of Gulf of Maine lobsters trucked to a

local cannery once they become berried due to Canadian regulations. Population genetic analyses identified significant structure in the southern population but no significant evidence for isolation by distance. These demes are probably the result of genetic drift, with limited gene flow or migration, following postglacial expansion of the species north. The eight demes identified in the southern population are largely consistent with the known seasonal movements of adult lobsters from tagging studies but not with the extensive broadcast of larvae from drift and modeling studies. This discrepancy could be explained by a strong homing behaviour in lobsters that directs them to their birth location on reaching maturity.

Reflections on Pelagic Transport and Settlement: Modeling Results and Future Work

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Over the past two decades there has been a great expansion of the benthic settlement work Richard Wahle conducted for his Ph.D. One of the research themes has been the quantitative relationship between pelagic postlarvae and newly settled lobsters, which we explored together in a series of field experiments during the 1990s. Our results indicated a strong positive relationship with the initial settlement phase, and the relationship held over a range of spatial scales. With this foundation, we embarked with a number of our colleagues to build a spatially explicit model of the early life history of lobsters at the Gulf of Maine scale, from egg production to postlarvae that were competent to settle. The predicted spatial and temporal patterns of postlarval abundance were compared with an abundance of postlarval data and with along-shore settlement patterns from field work. The comparison provided an evaluation of many variables important to such modeling, including the estimation of egg production patterns, the individual-based modeling parameters used for larvae and postlarvae, and dispersion rates used in the circulation model. We calculated connectivity matrices for lobster reproduction in the Gulf. I will discuss model results and suggest some future directions for research.

Understanding the interannual variability in American lobster (*Homarus americanus*) settlement

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The past twenty years of American lobster settlement index data shows immense spatial and temporal variability. This variability has also been captured in American lobster larval transport models. Studies have shown pre-settlement processes to be the dominant driver of local and regional lobster recruitment to suitable benthic settlement habitats. Time-lagged spatial correlation analysis represents one way to evaluate hypothesized larval sources and identify likely environmental factors important to local recruitment. For my Masters thesis I shall be performing spatial correlation analysis using lobster settlement data from the regions with the longest time series and various environmental variables (SST, wind, etc.) within the Gulf of Maine and southern New England shelf waters. Data on the spatial distribution of egg-bearing

females will contribute to this analysis. This study will benefit coupled biophysical models of lobster larval connectivity by identifying regions of larval release and environmental variables that are highly correlated with the spatio- temporal variability in settlement.

From *Homarus* to Diversity: Changing fishery and oceans management drivers for research on recruitment habitats for *Homarus americanus* in the Bay of Fundy, Gulf of Maine

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Prior to the 1990's, most field research on Homarus americanus populations in the Bay of Fundy had been conducted using trap-based approaches, emphasizing spatial and temporal trends in trap size-frequency distributions, as well as seasonal and inter-annual movement patterns. During the early 1990's the rapid expansion of salmon aquaculture in the lower Bay of Fundy brought attention to the dearth of information on the spatial distribution of spawning and recruitment habitats – essential components of the life-cycle of lobsters - critical for sustained production, and potentially at risk from coastal development pressures.

As part of synoptic lobster surveys in the lower Bay of Fundy from 1989 to 1993, a long-term annual lobster settlement monitoring program was established in 1991 at Beaver Harbour, New Brunswick. Results have been contributed into the regional settlement index, providing a crucial geographical outlier to the predominantly US-based sampling in Maine and southern New England. Although there has been limited expansion of settlement monitoring to other geographical locations at different times, Beaver Harbour represents the only long-term Canadian sampling site for lobster settlement monitoring.

Through the 1990's, coastal aquaculture development remained a key driver for a series of additional studies that incorporated benthic suction sampling to address interactions between lobster habitat use and aquaculture siting. Most recently, along with the introduction of passive settlement collectors as a monitoring tool, there has been increasing attention paid towards developing a better understanding of benthic diversity within complex sub-tidal cobble-boulder habitats.

In my presentation I will briefly cover the historical development of the Bay of Fundy lobster settlement monitoring program, and provide examples of applications of suction sampling techniques and habitat characterization for research on lobster:aquaculture interactions.

There has been limited capacity within Canada to develop balanced monitoring across geographical areas. New approaches (collectors) and new drivers (biodiversity and conservation planning) provide opportunities to refocus regional sampling programs into the future to more comprehensively address the ecological role of lobsters and ecological function of cobble-boulder habitats within the Gulf of Maine system.

Large-Scale Coherence in New England Lobster Settlement Associated with Regional Weather

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Consistent long-term ecological data sets are depressingly rare. Even more rare are data sets that also span large areas. Thus, the American Lobster Settlement Index data set provides a unique opportunity to examine how an ecological process varies in space and time and what processes drive the variability. Lobster settlement across New England exhibits a high degree of spatial correlation. The correlation patterns partition the settlement sites into a northern group (Maine and New Brunswick) and a central group (Massachusetts exclusive of Buzzards Bay). Each group has significant correlations between sites within the group, and there are some intriguing correlations across the groups. The large-scale pattern of correlations suggests that variability in settlement is related to large scale processes. We examined the association between settlement at six reference regions (Beaver Harbor, NB, Midcoast, ME, Beverly-Salem, MA, Cape Cod Bay, MA, Buzzards Bay, MA, and Rhode Island) and monthly mean weather conditions (geopotential height, temperature, meridional and zonal winds, and wind curl, all at 700mb) from the North American Regional Reanalysis. Using data through 2004, settlement at all of the four northern regions exhibited strong positive correlations with September geopotential height. Correlations were also found with temperature (positive) and curl (negative), with temperature being a stronger indicator in the north and curl a stronger indicator in the south. Buzzards Bay and Rhode Island were correlated with zonal winds in September and August, respectively. Excluding Beaver Harbor, these relationships also held for 2005-2008 and were especially strong at Midcoast and Beverly-Salem. The analysis suggests that the dramatic increase in settlement at Beaver Harbor since 2005 was not tied to a change in regional weather patterns and could be due to a more local process.

Lobster Settlement and Recruitment: What a long strange trip it's been

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Over the past 20 years we have come to understand where, when and how lobsters settle and recruit to benthic habitats. It is clear that settlement drives demography in this species both in space and in time. Persistent settlement hotspots and coldspots correspond with hotspots and coldspts in lobster landings. In fact, the American lobster is one of the easiest marine organisms in the world to quantify for settlement and recruitment. This is because they settle primarily in a specific habitat in relatively shallow (scuba diving depth) water. Further, lobster vagility increases ontogenetically. They remain within meters of their settlement location in their early benthic phase, their range increases during their adolescent phase (especially as they approach reproductive maturity) and averages over 30 km after reaching reproductive maturity. As a result of these characteristics, much more information about lobster demography can and should be extracted from detailed size/frequency analyses. Such an analysis suggests active size segregation occurs in coastal zones and the recruitment dynamics along the continental shelf fundamentally differs between southern New England (eg south of the Great South Channel) and

Georges Bank. These differences in recruitment are evident in size/frequency analyses but their dynamics have largely been ignored because rates of settlement are too low to quantify.

The use of lobster settlement collectors in coastal Nova Scotia: Lessons to date and future directions.

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Development of a lobster settlement index time series off coastal Nova Scotia is in its infancy. Settlement collectors of the design of Wahle *et al.* were deployed in 2007 and 2008 at locations along coastal Nova Scotia. In Lobster Bay, 138 collectors were distributed over 4 shallow sites (< 12 m) and one deeper site (> 20 m) in 2007. A total of 79 settlers (<= 12 mm CL) were found for an overall density of ~ 1.0 m^{-2}. This compares to a density estimate of 0.7 m^{-2} from suction sampling at the shallow sites. In 2008, estimates of settlement density were much reduced: 0.06 m^{-2} (suction) and 0.13 m^{-2} (collectors). In both years settlers were found at lower density at depths > 20 m. Estimated settler densities at other sites along Nova Scotia ranged from 0.8 m^{-2} (Port LaTour in 2008) down to 0 (sites off Halifax in 2007-08 and off Cape Breton in 2009). A network of settlement index sites along coastal Nova Scotia would be valuable for a range of questions related to lobster recruitment and growth if issues related to site selection and scaling can be resolved. Diversity on rocky habitats could also be monitored. If a network along coastal NS is to be supported in the long-term, we advocate basing the network on settlement collectors. This method brings local fishermen into the project and retrieval is not as sensitive to weather conditions. Available data indicate settlement densities from collectors are reflective of the densities obtained by suction sampling.

The American Lobster Settlement Index at 20 years: Looking back/ looking ahead

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Setting the stage for the workshop, this talk provides a brief history of the growth of the American lobster settlement index, and reinforces the need to set priorities for its future. In late 1980s the new emphasis on “supply-side ecology” energized researchers to look to larval transport and settlement processes to explain population dynamics of marine species with complex life cycles. At the same time, the western Australian rock lobster fishery was demonstrating the power of a larval settlement index to forecast catch trends. The American lobster settlement index was initiated in 1989, soon after diver-based suction sampling proved useful in quantitative sampling of newly settled lobsters in their nursery habitats. Over two decades the survey has expanded to encompass many other lobster producing regions of New England and Atlantic Canada. Supported by state or provincial marine resource agencies in each region, the survey is done annually at the end of the summer settlement season. Data from the time series has provided valuable insights into the pre- and post-settlement processes influencing

lobster recruitment, as well as promising signs as a forecasting tool. It has been the springboard for numerous research projects, contributing to some 26 publications and reports. Since 2005, vessel-deployed passive postlarval collectors (wire mesh trays filled with cobbles) have been tested and deployed widely as an alternative tool to assess lobster settlement in zones where diving is unsafe or impractical. This is especially true in Atlantic Canada. As we enter the third decade of the region-wide collaboration, it will be important to continue to evaluate the value of the index to stock assessment, forecasting, and a mechanistic understanding of lobster recruitment.

Distinguishing disease impacts from larval supply effects in a lobster fishery collapse

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We describe a time series analysis that differentiates the effects of variable larval supply and the mortality impact of shell disease on cohorts of the American lobster *Homarus americanus* in a southern New England, USA, coastal population. Prior to the onset of a shell disease epizootic in1997, larval settlement alone fully explained 82% of the variation in the numbers of pre-recruit lobsters about to enter the Rhode Island lobster fishery. With the onset of shell disease, however, the model required an additional term for disease prevalence to provide a sufficient statistical fit to the observed data. Neither time trends in bottom temperature nor predatory fish provided significant additional explanatory power for variability in pre-recruit abundance. To our knowledge, this analysis constitutes the first demonstration in which cohorts of a benthic marine invertebrate have been successfully tracked from settlement to the threshold of a fishery by accounting for the joint effects of variable supply of new recruits and subsequent disease during post-settlement years. As such, it illustrates how factors altering the rate of post-settlement mortality over time can obscure predictive relationships between settlement and subsequent recruitment. A tight spawner-to-recruit linkage is therefore unlikely in coastal Rhode Island. The analysis underscores the value of maintaining parallel time series of different life stages, as well as the need to better quantify both pre- and post-settlement mechanisms that influence cohort success in marine populations.

A vessel-deployed passive postlarval collector to assess settlement of the American lobster *Homarus americanus*

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Passive collectors are used widely in postlarval settlement and recruitment monitoring of spiny lobsters and crabs, but they have only been used in a limited way with clawed lobsters. For nearly two decades, diver-based suction sampling has served to monitor spatial-temporal patterns of American lobster (*Homarus americanus*) postlarval settlement and early juvenile abundance

in shallow near-shore nurseries. Collectors could reveal settlement patterns in zones beyond the practical limits of diving. In 2005, we launched a fisher-scientist collaboration to evaluate the performance of passive collectors designed to extend the reach of sampling, and to be deployable from a vessel equipped with a standard pot-hauler. Building on previous designs, our collectors comprised wire mesh trays lined with fine screening on the floor and walls and filled with cobble to simulate natural nursery habitat. Results indicate that no newly settled lobsters were lost during the retrieval process, and densities of young-of-year lobsters found in the collectors were similar to those in directly adjacent natural cobble habitat sampled by divers with suction samplers. The collectors also proved to be effective samplers of juvenile fish and crabs, suggesting a possibility for wider application. This success bodes well for expanded deployment of cobble collectors to broaden our understanding of the recruitment processes of lobster and other cobble-dwelling fauna along the coast of New England, United States and Atlantic Canada.

WORKSHOP AGENDA

Friday

10:00 AM	Arrivals / Shuttles to Burnt Island		
12:00 PM	Lunch		
Workshop talks: Looking back			
1:00 PM	Rick Wahle	(Bigelow Laboratory)	*Welcome / Opening Remarks*
1:10 PM	Rick Wahle	(Bigelow Laboratory)	*The American Lobster Settlement Index: Looking back/Looking ahead*
1:40 PM	Stan Cobb	(University of Rhode Island)	*Herrick's contemporaries: The OTHER lobster biologists*
2:10 PM	Lew Incze	(University of Southern Maine)	*Reflections on Pelagic Transport and Settlement: Modeling Results and Future Work*
2:40 PM	Andrew Pershing	(University of Maine / GMRI)	*Large-Scale Coherence in New England Lobster Settlement Associated with Regional Weather*
3:10 PM	**Coffee Break**		
3:30 PM	Louise Gendron	(DFO, Canada)	*Lobster benthic settlement in the Magdalen Islands, Québec, from 1995 to 2008*
4:00 PM	Gareth Harding	(Bedford Institute of Oceanography)	*Interpreting the genetic structure of the American lobster* (Homarus americanus)*, throughout its range, in relation to present-day, adult migrations and larval dispersion*
4:30 PM	Bob Steneck	(University of Maine)	*Lobster Settlement and Recruitment: What a long strange trip it's been*
5:00 PM	Michael Fogarty	(NOAA Northeast Fisheries Science Center)	*Lobster Population Dynamics in a Changing World -- the Role of Monitoring in Management and Assessment*
5:30 PM	Shuttles to mainland		
6:00 PM	Refreshments		
7:00 PM	Lobster dinner		
8:00 PM	Slides, Movies & Bob's *Blast from the Past*		
TBA	Shuttles to mainland		

Saturday

7:00 AM	Breakfast shuttle from mainland		
7:00 AM	Breakfast		
8:00 AM	Workshop Shuttle from mainland		
Workshop talks: Looking ahead			
9:00 AM	John Tremblay	(DFO, Canada)	*The use of lobster settlement collectors in coastal Nova Scotia: Lessons to date and future directions.*
9:30 AM	Diane Cowan	(The Lobster Conservancy)	*Lobster Nursery Habitats: How crowded can they get?*
10:00 AM	Michel Comeau	(DFO, Canada)	*Lobster early life stage monitoring and research: the southern Gulf of St. Lawrence perspective*
10:30 AM	Peter Lawton	(DFO, Canada)	*From Homarus to Diversity: Changing fishery and oceans management drivers for research on recruitment habitats for* Homarus americanus *in the Bay of Fundy, Gulf of Maine.*
11:00 AM	**Coffee Break**		
11:20 AM	Carl Wilson	(Maine DMR)	Discussion
12:50 PM	Rick Wahle	(Bigelow Laboratory)	Closing remarks
1:00 PM	Lunch		
	Afternoon activities - hike at Damariscove Island or Barters Island - shuttle to mainland for Boothbay Hbr, Midcoast Botanical Gardens, etc. - on Burnt Island - volley ball, frisbee, intertidaling (Low tide 15:05; +0.7ft) - or rainy day games		
Evening	Dinner on your own		
TBA	Boat Shuttles		

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AMERICAN LOBSTER SETTLEMENT INDEX PUBLICATIONS

Peer-Reviewed Publications (listed alphabetically)

Castro, K., Cobb, J.S., Wahle, R.A., Catena, J. 2001. Habitat addition and stock enhancement for American lobsters, *Homarus americanus*. Mar. Freshw. Res. 52: 1253-1261.

Chen, Y., M. Kanaiwa, L. Incze, and R. Wahle. In review. Forecasting cohort dynamics from young-of-year settlers for the American lobster using an individual-structured model. Submitted to Bull. Mar. Sci.

Cobb, J.S. and M. Clancy. 1999. Habitat based assessment of lobster abundance: a case study of an oil spill. Am. Fish. Soc. Symp. 22:285-298.

Cobb, J.S., M. Clancy, R.A. Wahle. 1999. In: L.R. Benaka (ed.) Fish habitat: Essential Fish habitat and rehabilitation. Habitat-based assessment of lobster abundance: a case study of an oil spill. Proceedings of the Sea Grant symposium on fish habitat, Hartford, CT 26-27 Aug. 1998. Am. Fish. Soc. Symp. 22: 285-298.

Fogarty, M.J. and L.W. Botsford. 2006. Metapopulation dynamics of marine decapods, pp. 271-320, in: P. Sale, J. Kritzer (Eds.), Marine Metapopulations. Elsevier, London, UK. 576 pgs.

Incze, L. S., and R. A. Wahle. 1991. Recruitment from pelagic to early benthic phase in lobsters (*Homarus americanus*). Mar. Ecol. Prog. Ser. 79: 77-87.

Incze, L. S., R. A. Wahle, and J. S. Cobb. 1997. Quantitative relationships between postlarval production and benthic recruitment in lobsters, *Homarus americanus*. Mar. Freshw. Res. 48:729-743.

Incze, L. S., R. A. Wahle, and A. T. Palma. 2000. Advection and settlement rates in a benthic invertebrate: recruitment to first benthic stage in *Homarus americanus*. ICES J. Mar. Sci. 57(2):430-437.

Incze, L.S., Wolff, N., Wahle, R.A. 2003. Can scientific observations of early life stages be scaled up to the level of a fished population? A case study using *Homarus americanus*. Fish. Res. 65: 33-46.

Incze, L. S., H. Xue, D. Xu, N. Wolff, R. A. Wahle, C. Wilson, R. S. Steneck, E. R. Annis, P. Lawton, and Y. Chen. 2006. Early life history and a modeling framework for lobster populations in the Gulf of Maine. J. Crust. Biol. 26(4):555–564.

James-Pirri, M.J., J.S. Cobb, and R.A. Wahle. 1998. Influence of settlement time and size on post-settlement growth in the American lobster (*Homarus americanus*). Can. J. Fish. Aquat. Sci. 55: 2436-2446

Palma, A. T., Steneck, R.S., Wilson, C.J. 1999. Settlement-driven, multiscale demographic patterns of large benthic decapods in the Gulf of Maine. J. Exp. Mar. Biol. Ecol. 241:107-136.

Palma, A. T., R. A. Wahle, and R. S. Steneck. 1998. Different early post-settlement strategies between American lobsters *Homarus americanus* and rock crabs Cancer irroratus in the Gulf of Maine. Mar. Ecol. Prog. Ser. 162:215-225.

Steneck, R. S. and C. J. Wilson. 2001. Large-scale and long-term spatial and temporal patterns in demography and landings of the American lobster, *Homarus americanus*, in Maine Fish. Bull. 52: 1303–1320.

Wahle, R.A. 1993. Recruitment to American lobster populations along an estuarine gradient. Estuaries 16: 731-738.

Wahle, R.A. 2003. Revealing the stock-recruitment relationship in lobsters and crabs: Is experimental ecology the key? Fish. Res. 65: 3-32.

Wahle, R. A., and M. J. Fogarty. 2007. Growth and Development: Understanding and modelling growth variability in lobsters. Pages 1-44 in B. F. Phillips (ed.) Lobsters: Biology, Management, Aquaculture and Fisheries. Blackwell Publishing, Oxford. 506 pp.

† Wahle, R. A., M. Gibson, and M. J. Fogarty. 2009. Distinguishing disease impacts from larval supply effects in a lobster fishery collapse. Mar. Ecol. Prog. Ser. 376: 185–192. doi: 10.3354/meps07803

Wahle, R. A., and L. S. Incze. 1997. Pre- and post-settlement processes in recruitment of the American lobster. J. Exp. Mar. Biol. Ecol. 217:179-207.

Wahle, R. A., L. S. Incze, and M. J. Fogarty. 2004. First projections of the American lobster fishery recruitment using a settlement index and variable growth. Bull. Mar. Sci. 74:101-114.

Wahle, R. A., and R. S. Steneck. 1991. Recruitment habitats and nursery grounds of the American lobster *Homarus americanus:* a demographic bottleneck. Mar. Ecol. Prog. Ser. 69:231-243.

Wahle, R. A., C. Wilson, M. Parkhurst, and C. E. Bergeron. 2009. A vessel-deployed passive postlarval collector to assess settlement of the American lobster *Homarus americanus*. Mar. Freshwat. Res. 43: 465 -474.

Xue, H. L. Incze, D. Xu, N. Wolff, N. Pettigrew. 2007. Connectivity of lobster populations in the coastal Gulf of Maine, Part I: Circulation and larval transport potential. Ecological Modelling 210: 193–211.

† Selected as Editors' Choice, *Science* 323, 3/13/09 issue

Technical Reports

Gibson, M. 2008. Lobster Settlement and Abundance in Rhode Island: An Evaluation of Methoprene Application and Other Factors Potentially Influencing Early Survival. RI DEM/DFW Report. 24 pp.

Lavalli, K. L., and R. K. Kropp. 1998. Abundance of juvenile lobsters at a new outfall site: Comparisons with inshore abundances and discussion of potential outfall impacts on lobster populations. Massachusetts Water Resources Authority, Environmental Quality Department, Boston, MA. 27 pp.

Wahle, R. A. 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008. Updates: New England lobster settlement index. Reports to Maine Department of Marine Resources, Rhode Is. Dept. Environmental Management, and Maine Lobstermen's Association. 2 pp. each.